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Structural degradation of a large composite wind turbine blade in a full-scale fatigue test

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Xiao Chen is currently a research scientist in the area of structural failure and integrity of large composite rotor blades and their subcomponents, with a particular interest in understanding failure response and characteristics associated with multiple structural nonlinearities.

Wind turbine blades are expected to sustain a high number of loading cycles typically up to a magnitude of 1,000 million during their targeted service lifetime of 20-25 years. Structural properties of composite blades degrade with the time. Although substantial studies, such as [1,2], have been carried out at a coupon level to characterize fatigue degradation of composite materials, there is no much study focusing on fatigue degradation of rotor blades at a full-scale structural level. Do structural properties of composite blades degrade in a similar manner to what has been observed in material tests at a coupon level? What might be the concerns one should take into account when predicting residual structural properties of rotor blades?

To answer, at least to a partial extent, these questions, this study conducts a full-scale fatigue test on a 47m composite rotor blade according to IEC 61400-23 (ed. 2014). A conventional single-axis mass resonance excitation (rotating mass) method is used as it is now still widely used for blade certification. The blade is tested in a flap-wise bending direction

with the suction side primarily under compressive stress and pressure side under tensile stress, see Fig. 1. The applied loads are increased to reduce the number of cycles to 2.0 million cycles. Bending stiffness of the blade is measured at different span-wise sections during the fatigue test in order to measure its possible degradation. Natural frequencies and damping ratios are measured both before and after fatigue test. Post-fatigue damage of the blade is examined throughout the blade.

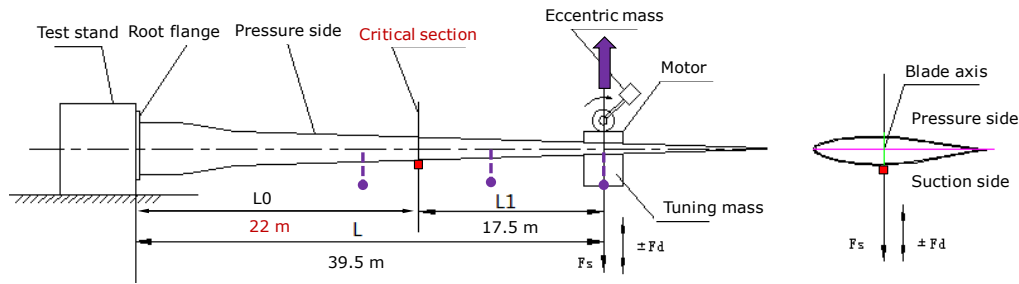
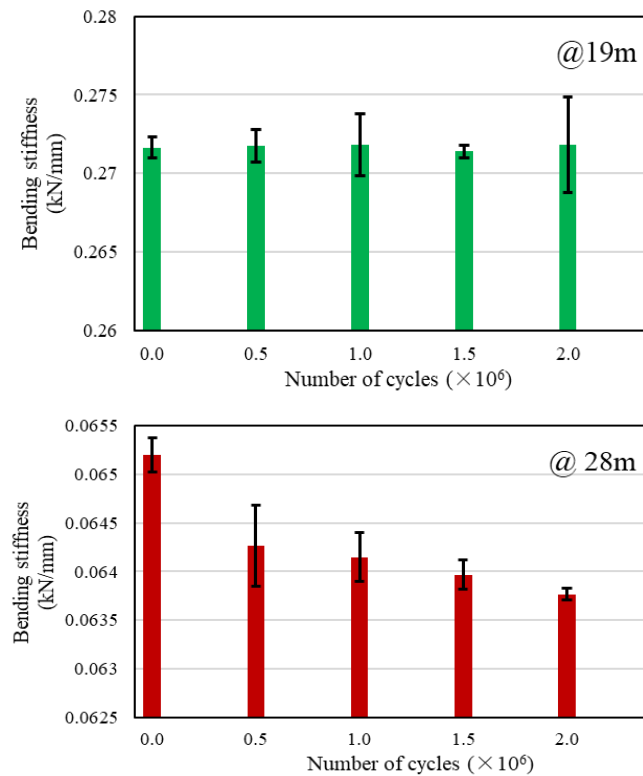


Fig. 1 Fatigue test setup

It is found that the blade exhibited different stiffness degradation patterns at different cross sections. As shown in Fig. 2, the bending stiffness of the blade from 0 to 19 m did not show obvious degradation during fatigue test. However, the bending stiffness of the blade from 0 to 28 m and that from 0 to 39.5 m showed very similar degradation pattern to composite materials, which is fast at the early stage and slow at the following stage. In addition, it is noted that the overall stiffness degradation is shown to be not significant.



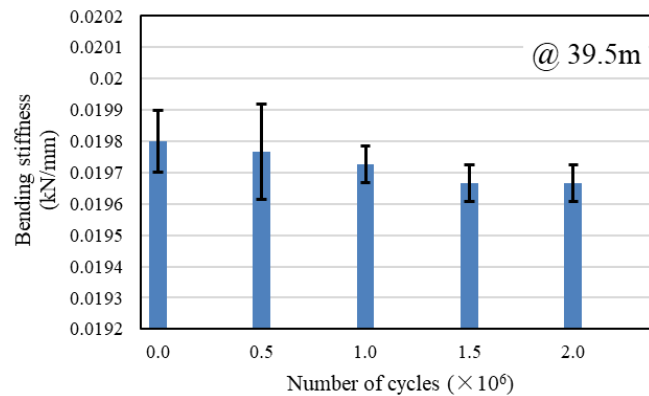


Fig. 2 Degradation of bending stiffness at different blade sections

This trend may be explained by the stress/strain levels experienced by different sections. During the fatigue test, the blade was stressed most in the middle region approximately from 19 to 34 m where stiffness degradation is expected to be significant. This observation can be also verified by static load test as shown in Fig. 3.

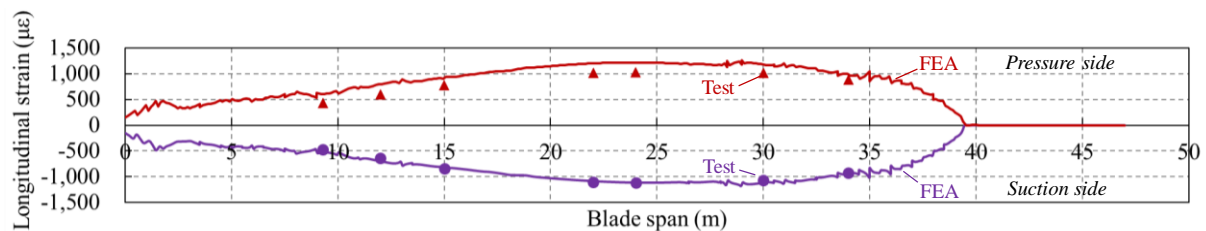


Fig. 3 Longitudinal strain distribution under static loads

The changes of natural frequencies due to fatigue are found to be negligible and they range from -0.4% to 0.3% for different vibrational modes. In addition, the changes of damping ratios for the flap-wise and edge-wise bending modes are found to be quite noticeable and they are 21% and 10%, respectively. For the torsional mode, a significant change, i.e., 45%, of damping ratio is observed after the fatigue test, see Table 1.

Table 1 Structural dynamics properties measured before and after fatigue

	Vibration mode	Pre-fatigue	Post-fatigue	Change (%)
Natural frequency (Hz)	1 st flapwise bending	0.663	0.66	-0.45
	1 st edgewise bending	1.227	1.22	-0.57
	2 nd flapwise bending	2.102	2.106	0.19
	2 nd edgewise bending	4.076	4.082	0.15
	1 st torsion	8.781	8.802	0.24
Damping ratio (%)	1 st flapwise bending	0.167	0.204	22.16
	1 st edgewise bending	0.153	0.166	8.5
	2 nd flapwise bending	0.295	0.357	20.9
	2 nd edgewise bending	0.08	0.089	11.25
	1 st torsion	0.084	0.122	45.24

Post-fatigue damages observed in the blade include the whitening of sandwich skins and cracks in core materials, and fracture of composite materials in the root transition region despite the calculated low stress level there. The findings from this study suggest that the change of damping ratio might be a more practical metric than stiffness degradation to indicate fatigue damage. In addition to fatigue properties of composite materials at a coupon level, special attention has to be paid to fatigue characterization of structural discontinuities, such as material change, geometric transition and manufacturing-induced defects, etc., in order to better understand fatigue behaviour of large rotor blades at a structural level.



Fig. 4 The whitening of sandwich skins after fatigue test

As for the future study, the following topics may be of interest:

- (1) Micro damage characterization to understand mechanism of damping ratio degradation.
- (2) Correlation between micro damages and macro structural behavior.
- (3) Fatigue damage prediction at regions with stress concentration and multiaxial stresses.
- (4) Structural health monitoring techniques based on damping ratio degradation.

References:

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